EXPERIMENTS WITH SINGLE TRAPPED YTTERBIUM IONS AT JPL

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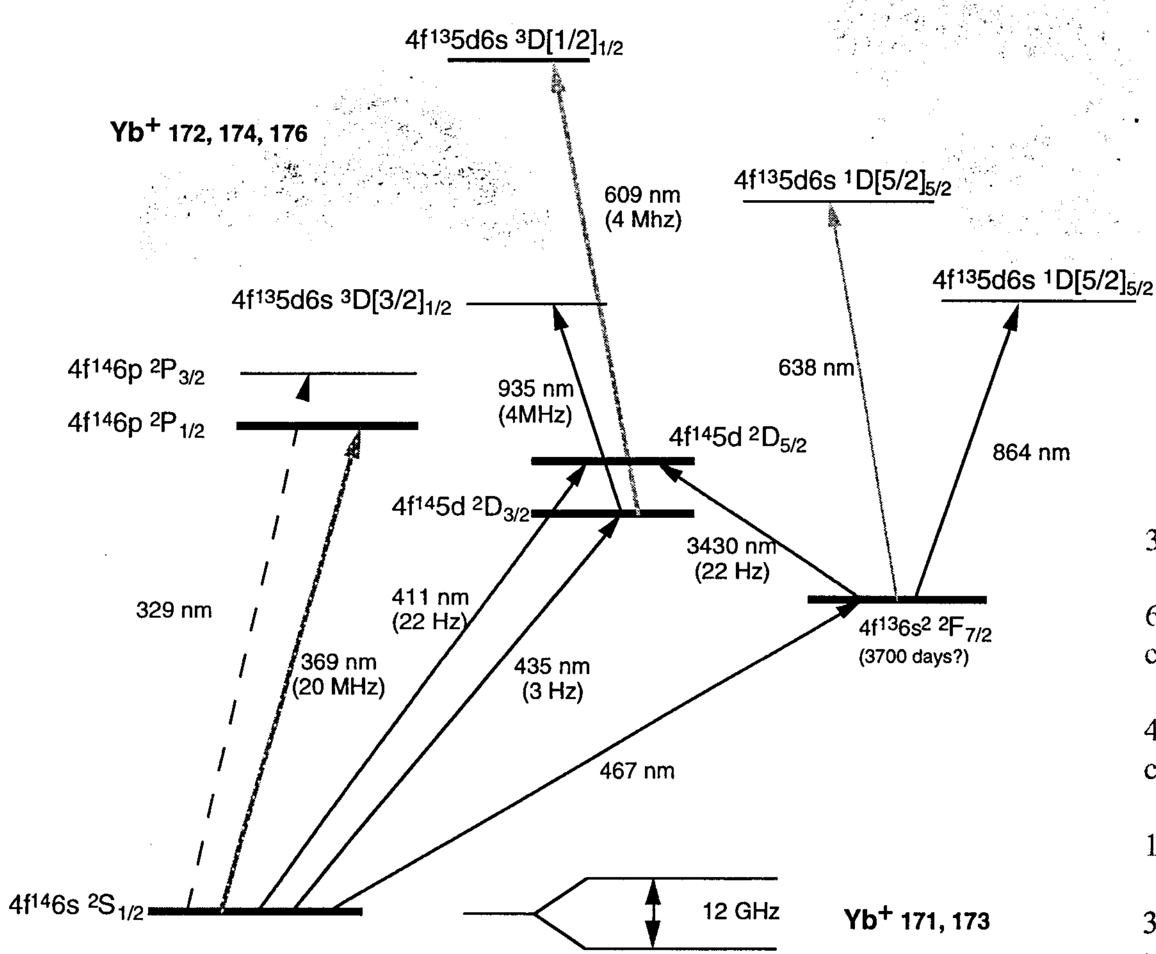
Ytterbium ion level scheme



369 nm cooling transition.

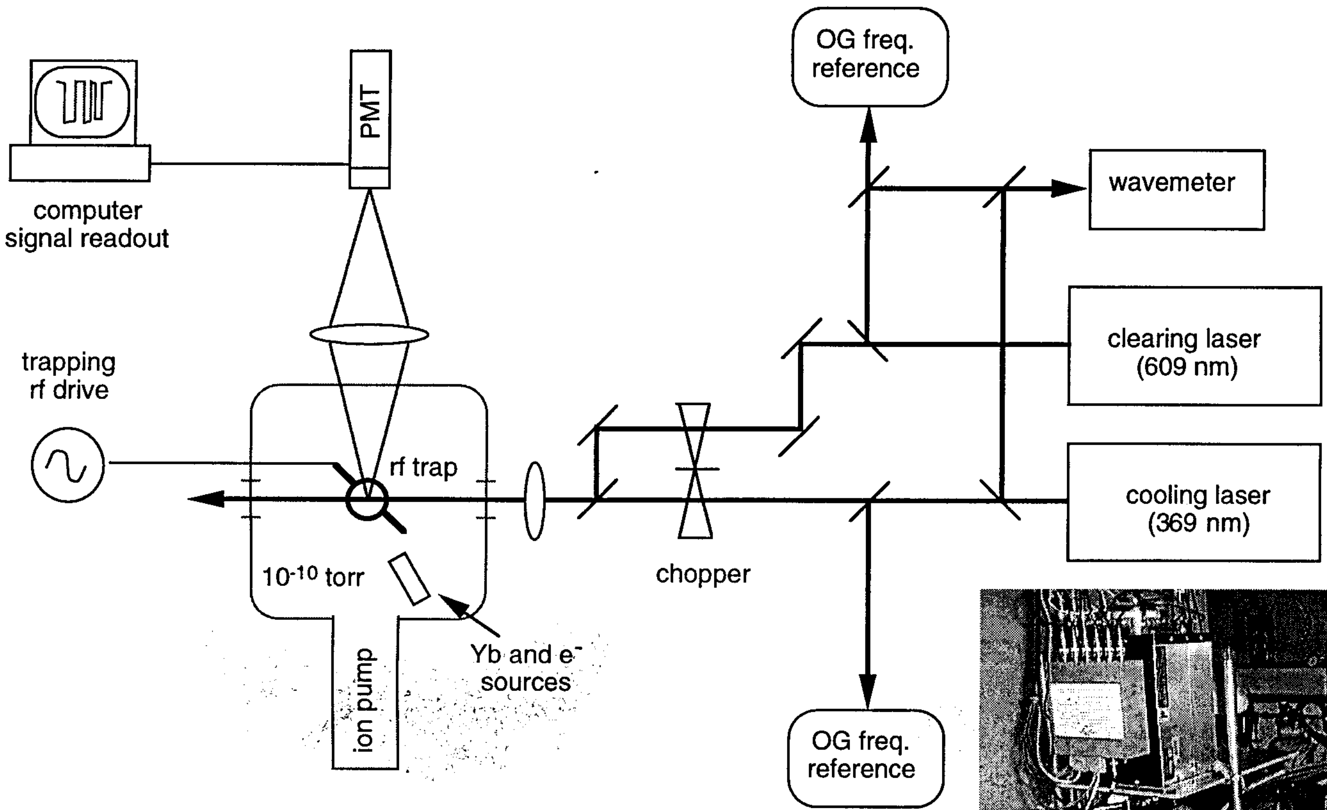
609nm 935nm, 638 nm clearing transitions.

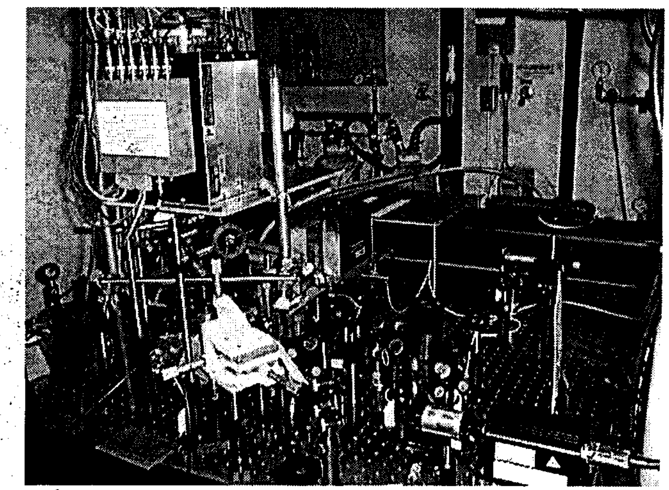
411nm, 467nm, 3.43um clock transitions.

12 GHz microwave trans.

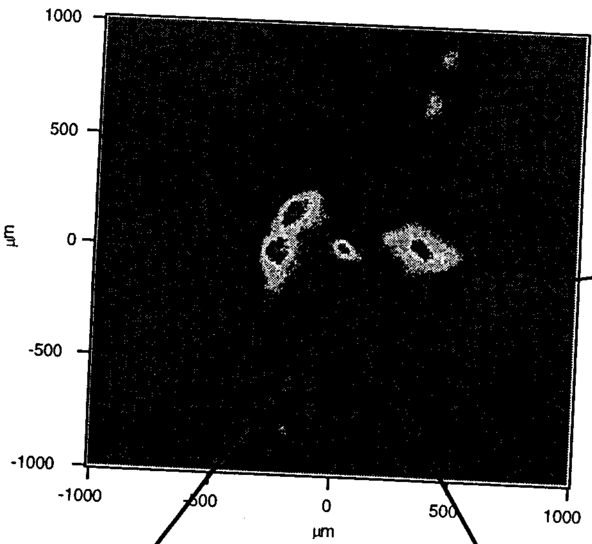
329 nm auxiliary shelving transition.

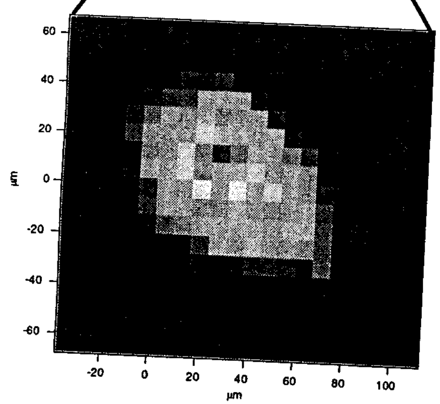
Sketch of basic experimental setup





Paul-Straubel rf trap and single ion image





Single Yb+ ion fluorescence image

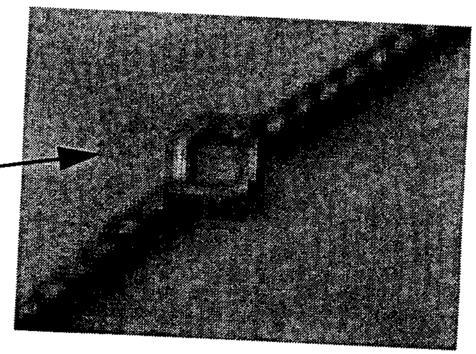
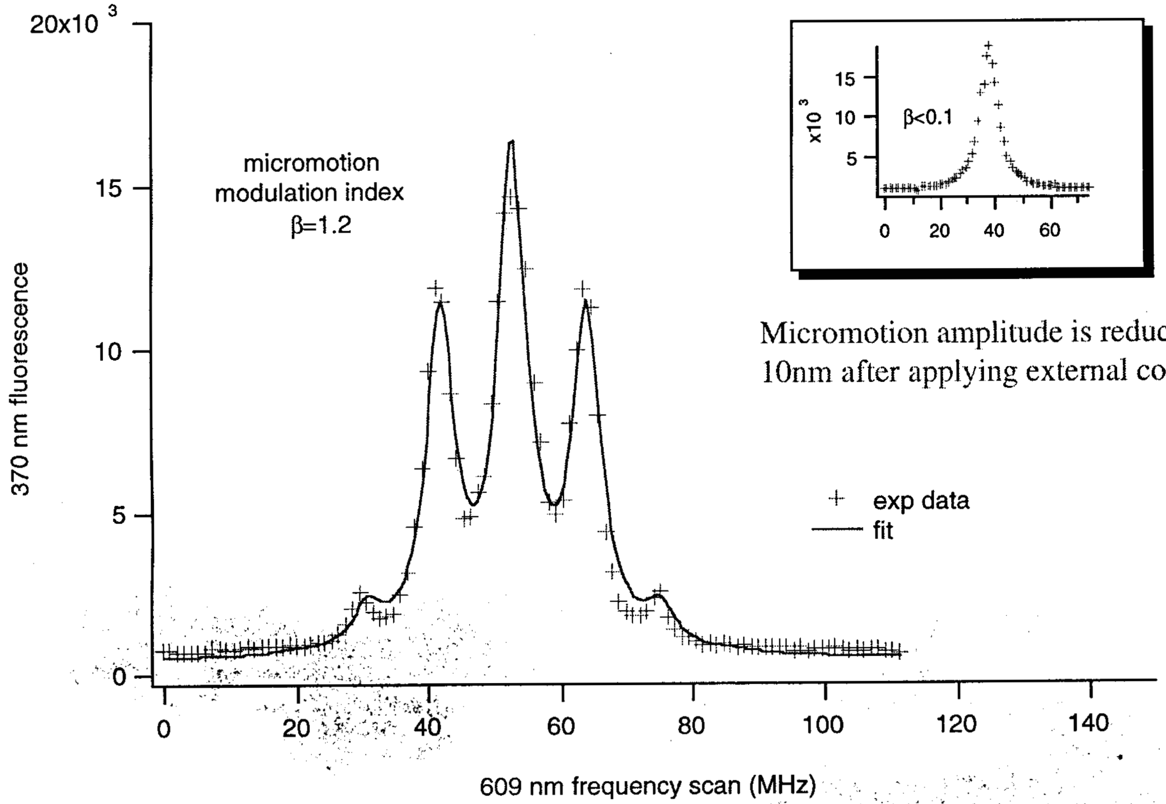


Photo of a Paul-Straubel trap

The trap is made of twisted Ta wire loop of 1.0 mm diameter.

The image resolution is limited by the photon collection optics (x4.5).

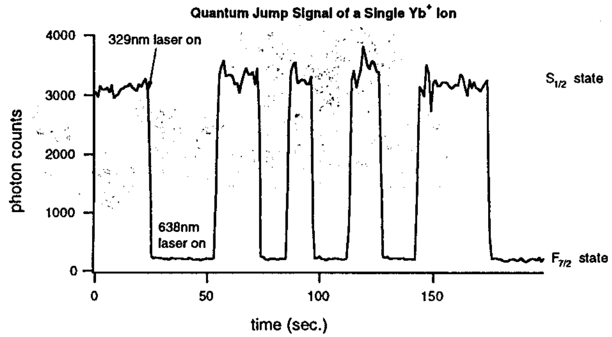
Resolved micro-motion sideband spectrum at 609 nm

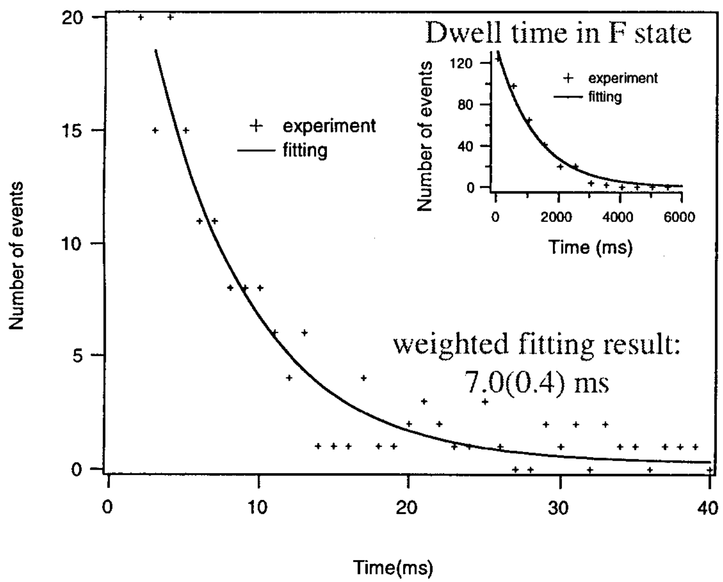


Micromotion amplitude is reduced to about 10nm after applying external compensation.

609nm transition has a width of about 4MHz, conveniently resolving the 11MHz micromotion modulation sidebands. In the case, the micromotion amplitude is about 120nm.

$D_{5/2}$ state lifetime measurement



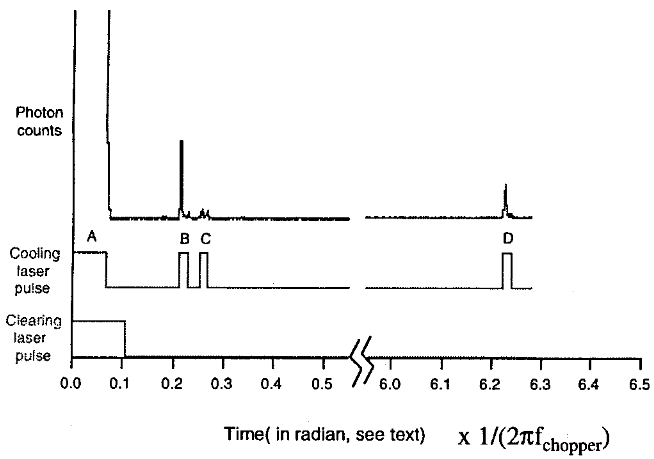


The lifetime of the $D_{5/2}$ state can be determined using the quantum jump technique. In this technique, continuous fluorescence photons are detected when the ion is in the ground state. An excitation of the ion into the $D_{5/2}$ state will quench the fluorescence completely until it decays spontaneously back to the ground state and the fluorescence resumes.

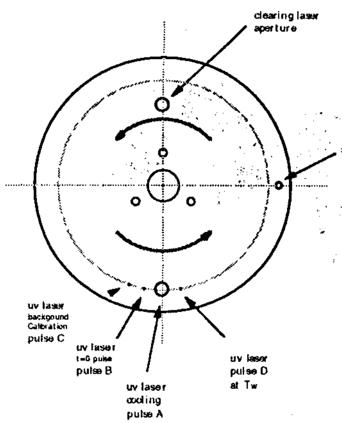
The on or off state of the fluorescence signal indicates whether the ion is in the $S_{1/2}$ or $D_{5/2}$ state. The average fluorescence off-time(dark period) gives the lifetime of the $D_{5/2}$ state.

$D_{3/2}$ state lifetime measurement

laser pulse sequence

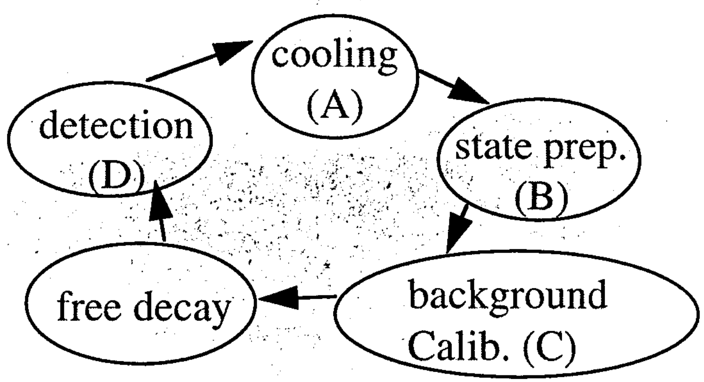


The lifetime of $D_{3/2}$ in Yb+ ion has been measured so far only with ion clouds in buffer gas, a condition not ideal for long lifetime measurement. It is not obvious how the measurement can be done with a single ion because the state is inside the transition cycle for the normal signal detection. *Our new technique takes advantage of the fact that the branching ratio of the $P_{1/2}$ decaying to the ground state is large, about 200.*



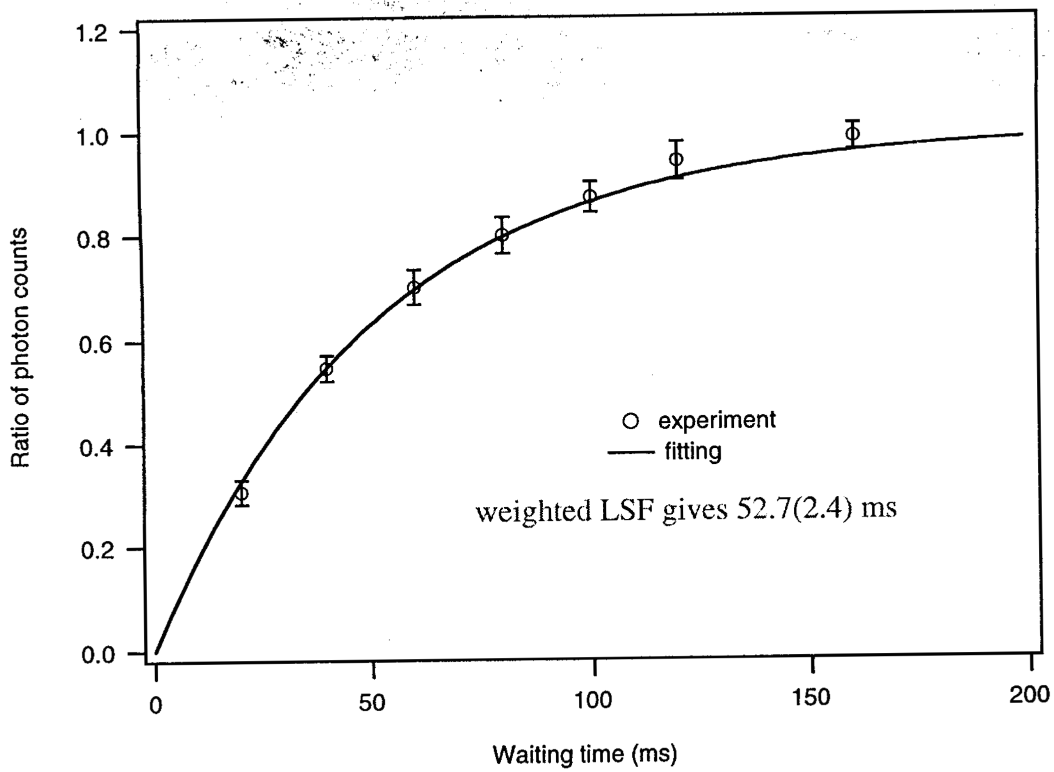
chopper blade for laser pulses

measurement cycle:



$D_{3/2}$ state lifetime measurement

decay histograph

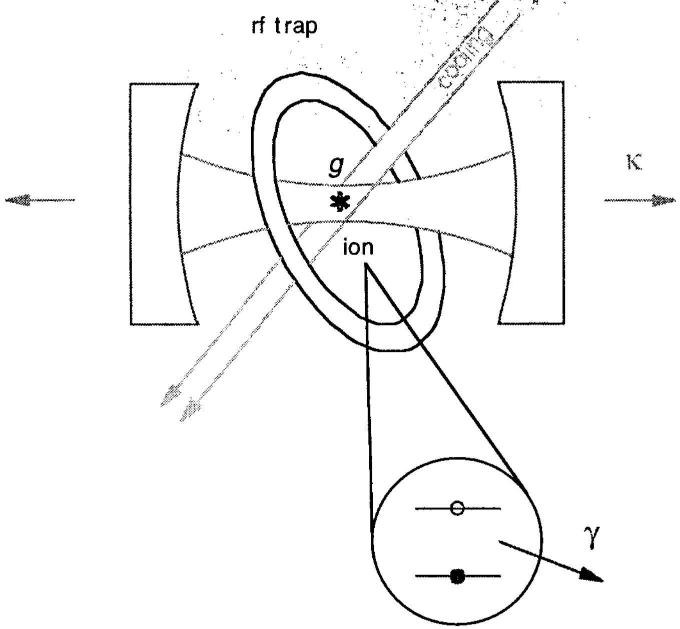


On average, 207 photons at 369nm are scattered before the ion is repumped into $D_{3/2}$ state again, yielding the $P_{1/2}$ branching ratio to be 0.0483.

Motivations for individual ions in a high-finesse optical cavity

- Standing-wave laser cooling
- CQED in the strong coupling regime, structure and dynamics
- Real time probing of atom CM motion and measurement
- Quantum logic and information processing
- Quantum information distribution and networking
- Single ion laser/novel light source

Trapped individual ions in an optical cavity



Interaction Hamiltonian:

$$\hat{H}_s = \frac{\hbar\omega_A}{2}\hat{\sigma}^z + \hbar\omega_c\hat{a}^\dagger\hat{a} + i\hbar[g(\vec{r})\hat{a}^\dagger\hat{\sigma}^- - g^*(\vec{r})\hat{a}\hat{\sigma}^+].$$

$$g(\vec{r}) = \left(\frac{\mu^2\omega_c}{2\hbar\epsilon_0 V_m}\right)^{1/2}U(\vec{r}) = g_0 U(\vec{r}).$$

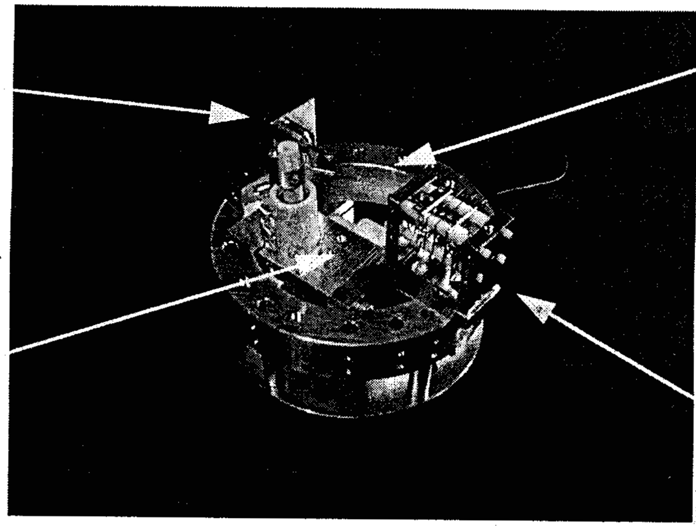
The strong coupling condition:

$$g_0 > (\gamma, \kappa).$$

Experimental challenges:
* protecting mirror coating,
* avoid/circumvent dielectric charge-up,
* reducing cavity volume,
* ....

Initial exploratory system: special design points

- translatable trap/ion
- collimated atom beam
- collimated/rf-synchronized electron pulse
- separate cooling laser beam and cavity laser beam
- uv access for possible *insitu* surface discharge



Initial exploratory system: experimental goals

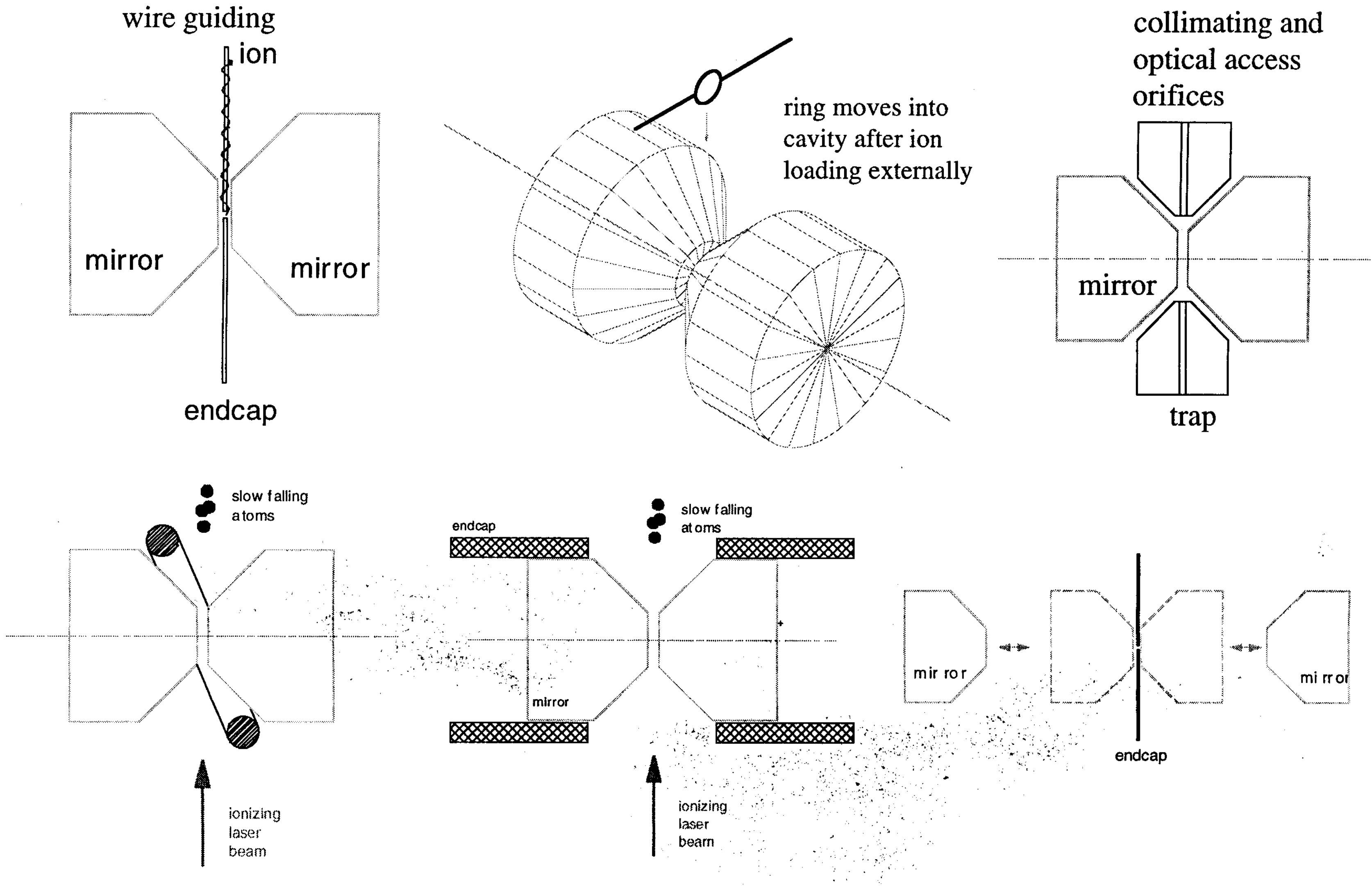
Feasibility demonstration:

- effects of atom beam collimation/contamination
- pulsed electron beam ion-loading/surface charge up problem
- ion translation capability, trap stability
- QED cavity locking/stabilization
- possible *insitu* surface discharge

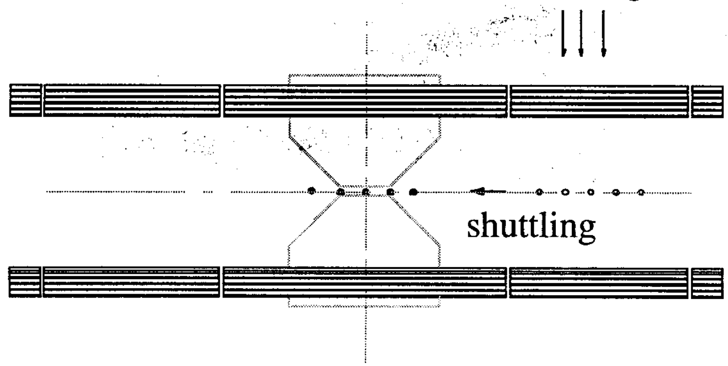
Interesting physics to investigate:

- sw cooling
- cavity field mapping
- ion orbital size measurement
- laser transmission of occupied cavity
- QND atom state measurement through off resonance phase shift

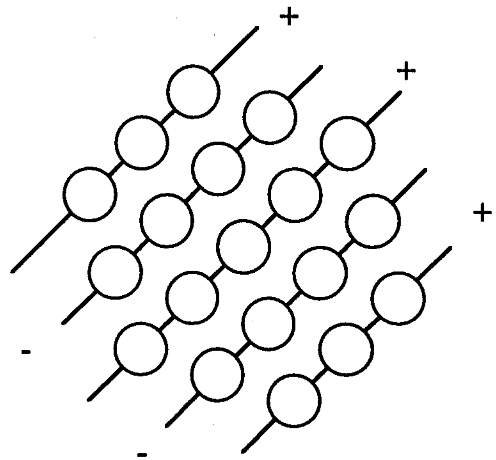
Future systems: trap-cavity integration I



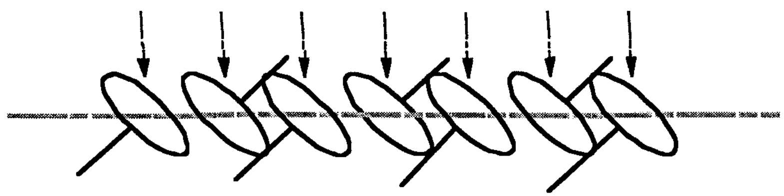
Future systems: trap-cavity integration II



linear trap ion loading and ion addressing



planar ring trap array



serial ring trap array